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System of Field Operations for Double-Cropped Paddy Rice Production Mechanization in South China

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Abstract. *Double-cropped paddy rice production in south China plays an important role in China's food security. This production system represents 42.5 percent of the total available paddy rice area resulting in 40 percent of China's total rice production. The field operation system in double-cropped paddy rice production area is complicated, and various technologies must be used in each field operation. For soil preparation, no-till approaches as well as plows or discs are used. For plant establishment, direct sowing and transplanting are used. Rice harvest can be accomplished using combine harvesting; mechanical reaping followed by manual collection and threshing. The choice of the most suitable technology in each field operation and the overall system of field operations affects the development of paddy rice production mechanization. With the pressing need to mechanize*

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paddy rice production, it is necessary to analyze various systems of field operations that could be used in this production system. A survey of farmers, including both those who do and do not own machinery, and managers of custom agricultural machinery cooperatives was completed using questionnaires and telephone surveys in six provinces and regions in China. The survey included questions about basic participant demographics; development environment and status of paddy rice production mechanization; different mechanization technologies, cost of labor and machinery utilization; and factors affecting machinery utilization cost. Subsequently, the mechanization options for each field operation were analyzed based on machinery availability, operation scale and organizational pattern. In addition, the economic benefit of different systems of field operations was compared. In total, there were 14 possible machinery systems. Among these systems, those that have the high economical benefit use plowing as the tillage operation, blanket-type seedling or seedling cultivation in the field, followed by transplanting, chemical application, and combine harvesting.

Keywords. Field operation, paddy rice production, double-cropping, China, machine systems

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Introduction

Rice is a staple food of China, with an annual planting area of 29,627 kha. Rice production reached 195 Mt in 2009 (China Statistical Yearbook, 2010), accounting for 36.8% of the country's grain production. Per capita rice consumption was 106 kg in 2009 (China Statistical Yearbook, 2010). With continuing population growth, the demand for rice is rising rapidly. Within this context, the harvested area is predicted to decrease 6.98% and the production to decline 1.5% approximately in China over the next 10 years (World Agricultural Outlook, 2010).

Developing the capability to increase production is important for enhancing domestic rice supply and insuring food security. Mechanical tools and technologies are one important means for increasing production. Rice is also the predominant crop in Japan and South Korea, where rice production conditions are similar to south China, but paddy rice production in these two countries has been highly mechanized. In Japan, paddy rice production has been mechanized since the 1970s. Ninety-nine percent of paddy rice transplanting in Japan was mechanized (Li Yaoming, et al., 2005). Also in South Korea, 100% of the tillage, 98% of the transplanting, 100% of the spraying and 99% of the harvesting of paddy rice production has been mechanized (Park et al., 2002). Paddy rice production is laborious and time-consuming, and it is difficult to be profitable under small production scales. Machinery and mechanical technologies can reduce manual labor requirement and production costs, and can also help with the transfer of the rural labor force to other industries, increase farmer income, and improve rice quality. It is estimated by the Division of Agricultural Mechanization of the Ministry of China. PRC (MOA.) that mechanical harvesting and transplanting can reduce the cost by US\$114/ha, and increase the yield by approximately one ton per hectare. Various machinery and technologies have been used in paddy rice field operations in a double-cropping production system. However, the level of mechanization is still low in China. One of the major obstacles is the lack of a strategy to choose the agricultural technology and machinery suitable for different field operations in particular regions.

A number of studies about paddy rice production mechanization focused on the machinery and technologies used for particular field operations, but did not investigate the interaction of different technologies for field operations in the production system context. The literatures on technologies concern on the following aspects. To establish plants, for example, precision hill direct seeding does not injure the crop, thus low tiller growth is not damaged, which could lead to higher yields (Tang et al., 2009). In double-cropping areas in south China, the focal point of paddy rice production development has been to develop blanket type seedling transplanting technology with seedling production in the field (Wu, 2005). The machinery for direct seeding and throwing transplanting are not technologically satisfactory (Fang, 2001), sowing rate accuracy and sowing leak for direct seeder is difficult to detect as described by Zheng(2004), and commercial throwing transplanting machine is still under development (Xiang 2007).

With the importance of paddy rice production mechanization and sustainability, systems of field operations for double-cropped paddy rice production mechanization in south China must be considered. This research analyzed the technologies and machinery used in each field operation, identified affecting factors and related problems. The objectives of this study were to (a) investigate the most suitable technologies and machinery for paddy rice production; (b) determine the most economically beneficial mechanical field operation system for paddy rice production in double-cropping regions in south China.

Background

Technologies of paddy rice field operation

Various technologies and machinery have been used to mechanize paddy rice production in double-cropping area in south China. For tillage, 80.35% of the cultivated area is mechanized 48.3% of the area is mechanically harvested, but only 2.88% is planted mechanically (MOA, 2009). Constraints on the adoption of machinery in this region include the special requirements particular to the region. The weather in this region typically has high levels of precipitation, humidity and temperature (Jiang, 2003). Many fields are small and can generally only be accessed by foot paths. Not all fields have irrigation systems, but those that do are generally flood irrigated through systems of small channels or field-to-field gates. Farmers have limited financial resources constraining their ability to purchase advanced machinery. Timeliness is also constraints on a double-cropping system. One of the most important advantages of adequate mechanization is the freedom that it gives the farmer to plan work in advance and to maintain a reasonable timetable to accomplish the principal farming operations (Culpin, 1975).

Methods of Tillage Operation

Paddy rice production starts with primary tillage (usually plowing) and field leveling. Paddy fields are filled with water before primary tillage operations to make the crop residues and topsoil soft. Typical machinery used in tillage operations include micro-size cultivators, mechanical tilling boats, or some tractor mounted implements, like rotovators, harrows and moldboard plows. Multifunctional operations combining plowing and seeding or fertilizer distribution are becoming more widely adopted, resulting in higher efficiency and lower cost. In contrast to the use of tillage for seedbed preparation, no-till practices have been tested and adopted in some parts of the region to protect the environment, since it cause less soil disturbance (Xu, et al., 2006).

Methods of Rice Planting

There are three methods of paddy rice planting in double-cropping regions in south China, (1) direct seeding, (2) transplanting, and (3) throwing transplanting, each of which can be done mechanically and manually. While 98% of the paddy rice was planted by transplanting (Wang et al., 2007), mechanized paddy rice planting in the double-cropping area in south China only accounts for 2.88% of the planted area. Of that planted mechanically, 7.34% is done by mechanical directing seeding, 15.46% using mechanical throwing transplanting, mainly in Jiangxi and Hunan province, and 69.03% is accomplished through mechanical transplanting (Mechanization Annals, 2009).

1. Direct Seeding

Direct seeding is one of the oldest methods of paddy rice planting (Wang et al., 2007). Seeds are planted directly into the production fields. Direct seeding is simple and less laborious. However, directly seeded plants tend to be easily affected by weather at the early growth stages, leading to difficulty in weed and insect control. This method requires high quality field tillage and has a higher risk of germination losses than transplanting in double cropped areas (Wu, et al., 2000).

2. Transplanting

The transplanting process requires that several requirements are met for good performance. The seedbed must be prepared for transplanting; seedlings must be grown for the particular transplanting equipment that will be used; and the transplanting equipment must be available for use and in good operating condition. For this method, seedlings are raised collectively in a nursery and planted orderly in rows. The early care of the seedlings and the row structure

resulting from transplanting enables ease in the control of weeds, insects and diseases. Mechanical transplanting uses small seedlings, with high survival and growth rates. This method is appropriate to be used for early and late crop plantings. The soil of paddy field should be soft and without crop residue on the soil surface, but firm at deeper levels with sufficient soil moisture content.

Self-propelled paddy transplanters were first developed and adopted in Japan and South Korea (Li, et al., 2005). Those transplanters use blanket type seedlings. Both walking and riding type models are available. Riding type machines are generally plant 4 to 6 rows while walking type generally plant 2 to 4 rows.

3. Throwing transplanting

Throwing transplanting was adopted in the 1990s (Yuan, et al., 1998). In this method, seedlings are raised in a seedling tray. When the seedlings are mature enough to be planted, the seedlings are laid on the transplanter. After a series of automatic procedures, a shooting mechanism will throw tray-grown seedlings onto the soil surface. Farmers use this method to plant early and late crops. Seedlings are planted randomly in the fields, thus resources like light and water may not be used efficiently. The performance of throwing transplanting can be easily affected by weather and generally results in high plant establishment losses compared with conventional transplanting. Improvements in throwing transplanting machinery have been investigated using an air jet to distribute the seedlings in a more orderly fashion (Xiang et al., 2007).

Methods of Rice Seedling Establishment

High yield planting technologies combined with standard seedling establishment technologies are important in a successful mechanical transplanting system. There are three seedling cultivation methods: (1) Blanket type seedling establishment, that can use soft plastic bowls, hard plastic bowls or double-layer plastic sheets, which hold the planting media and are divided into separate seedling cells, (2) Rice pot seedling establishment which uses soft plastic or hard plastic trays, and (3) Open-field seedling establishment, which use double-layer plastic sheets. Seedlings can be grown using double-layer plastic sheets or plastic bowls at 75% of the cost of the open-field method (MOA). Plant seedling establishment under controlled conditions can provide more seedlings in a short time, but if the cost is too much, it will not be adopted widely.

1. Blanket type seedling establishment

This method is used to raise seedlings for mechanical transplanting. Some farmers use this method even for manual transplanting. Seedlings are raised in standardized blocks, which are 58 cm long by 28 cm wide. The soil is 2-2.5 cm thick; when the seedlings are 21 days old and 12-17 cm in height, they are ready to be planted. Seedlings can be rolled like a blanket with roots facing outside and carried to the transplanting site. The interlocked roots are loosened carefully before transplanting. 3-4 seedlings should be transplanted per cell.

2. Rice pot seedling establishment

This method uses soft or hard plastic trays to raise the seedlings and each seedling is separate. When the seedlings are ready to be planted, they are pulled out from the tray and distributed in the field through throwing transplanting (Song, 2005). The seedlings fall into the mud making up the field surface, take root, and can grow quickly. Rice pot nursery is typically used in north part of China, and in south China, it has also been adopted.

3. Open-field seedling establishment

This method includes two types of seedling cultivation depending on field conditions. The first method is the dry land method and is used in areas with limited water availability. It requires

less water, but requires high seeding populations because of the low germination rate. The second method is the wet bed method which is widely adopted and requires a lower seeding population; seedlings are strong and will recover quickly after being transplanted. The wet bed method also takes a longer time for seedbed preparation, and the seedlings cannot be kept for a long time.

Chemical Application

Pre-emergent fertilizers, herbicides and insecticides are applied to paddy rice fields, especially in double-cropping areas in south China, where the weather changes substantially during the growing season and insect and plant disease occur frequently. Chemicals can be applied at different times, in many ways, with knapsack sprayers or hand sprayers.

Harvesting

Mechanical harvesting technology is desired by farmers in double-cropping areas in south China, because in double cropping areas, quick removal of one crop will permit a valuable second crop to be sown and harvested (Culpin, 1975). Nevertheless, the mechanization level in south China of the harvesting process was only 48.3% in 2009. There are two mechanical harvesting methods. One method is combine harvesting, and the other is reaping and threshing.

1. Combine harvesting

Combine harvesting involves cutting, threshing, cleaning and transporting the grain in the field with one machine. This method can be divided into full-feed and semi-feed combines depending on the amount of crop that is cut and fed into the combine. Full-feed combines cut the whole rice plant and feed it through the combine. If only the heads are fed into the combine, it is called semi-feed harvesting. During the harvest season of the early rice crop, heavy rains are common. Rice harvesters need to have good performance in threshing and cleaning. The chaff must be cleaned from grain thoroughly; otherwise it may lead to grain heating and spoilage because the grain cannot be dried in a timely manner (Jiang, 2003). Paddy fields are small, so 4-6 row semi-feed combines and small-size full-feed combines with moderate price are preferred for the south China multiple cropping context.

2. Reaping and threshing

Reaping and threshing is another harvesting method. An angular sickle is still used widely to manually reap paddy rice, which has soft but tough straw and is easily shattered (Quick and Buchele, 1978). The cut rice is bundled and transported to a stationary thresher in the field or at the farmstead.

Methods and Materials

Description of Research Method

Questionnaires, telephone surveys, and onsite surveys were carried out by the China Agricultural Mechanization Development Research Center in the double-cropping rice production region of south China. The survey covered six provinces and regions including Jiangxi, Fujian, Hunan, Guangdong, and Hainan provinces and the Guangxi Zhuang Autonomous Region. For this study 15 counties were selected randomly as samples. About 10 farmers were chosen randomly as sample farmers in each county. In total, 120 participants took part in the survey, and were interviewed with the structured questionnaire; resulting with 112 valid questionnaires which qualified for the analysis. The other eight questionnaires are not qualified for analysis either because they were incomplete or contained unreasonable answers.

Mechanization adoption level data was acquired from MOA. Additional information on paddy rice production practiced by farmers was also gathered from literature.

The specific questions covered by the questionnaire were: 1. Demographic information of the participants engaged in paddy rice cultivation; 2. Cultivation practices; 3. Machinery used for different field operations; 4. Cost of the machinery utilization and fuel consumption; 5. Farmers' socio-economic conditions, like education level, work experience about machinery operation, income and outcome. A translated questionnaire used for the research is included in the appendix.

Data from the survey were entered into Excel for analysis. The number of farmer participants using each machine option for particular field operation was calculated, and the adoption percentage was calculated by equation 1, indicating the percentage of survey participants who accept a certain technology.

$$P_i = \frac{N_i}{T} * 100\% \quad (1)$$

where P_i is the percentage of respondents adopting mechanization category i ,

N_i is the number of respondents adopting mechanization category i , and

T is the total number of respondents.

Mean values and standard deviation of different machinery custom operation rates obtained from the survey were used for analyzing the cost of production systems. Demographic information of survey participants, like farmers' age and education level, as well as the paddy rice production conditions, like field size and field location were aggregated.

Field size data were divided into four groups, survey respondents whose fields are (1) less than 1 ha, (2) 1 to 3 ha, (3) 3 to 5 ha, and (4) over 5 ha. The education level of farmers was divided into 5 groups according to the number of years that the respondents were enrolled in formal education. The field terrain was divided into 3 categories: (1) plain, (2) hilly and (3) mountainous.

Labor cost was calculated through the multiplication of working days needed multiplied with labor price per day. In this region, CNY 60 (US\$9.10) per day was used. The yields of different production systems were obtained through the questionnaire interview, combined with yield estimates on the literature, other cost like seeds, fertilizers and seedling trays and bowls were obtained from the survey, and average value were used in the analysis. The income rice production systems were obtained by multiplying of rice yield estimates by national rice procurement prices.

Results and Discussion

Paddy rice field operation systems

Typical field operation systems in double-cropping area in south China were obtained from the survey. Cultural practices implemented through a system field operations constitute of four parts, including tillage, planting, crop protection, and harvesting (Figure1). In this region, chemicals were applied for crop protection using a hand sprayer or knapsack sprayer, only a small portion was done mechanically, so in the paper, crop protection was not considered in production systems.

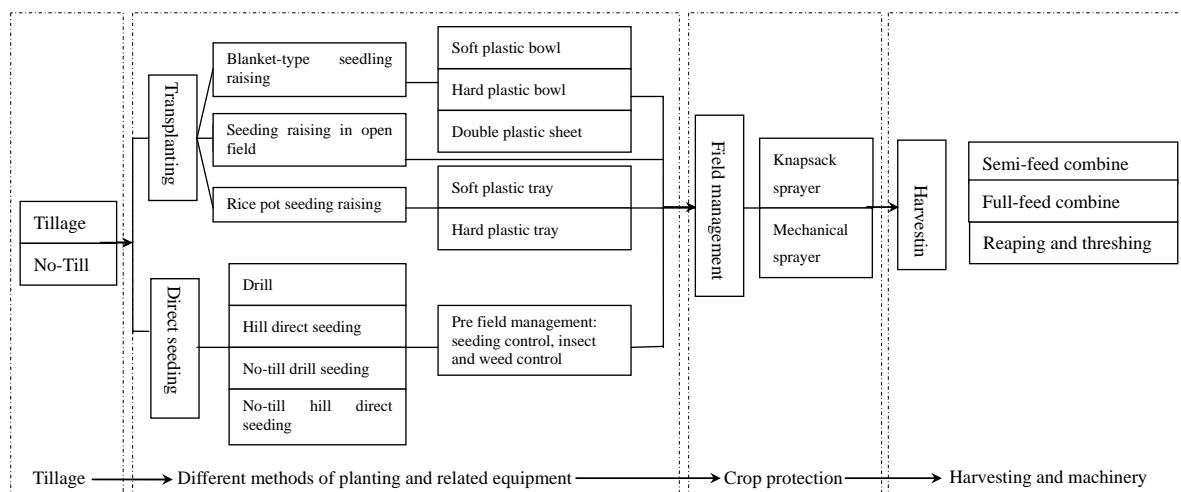


Figure 1 Paddy Rice Field Operation System in South China

According to the survey and literature review, there are 14 possible field operation systems in double-cropping area in south China (Table 1). The systems were different combination of technologies used for each field operation. The first six systems (1-6) employ no-till practices to reduce soil disturbance. The last eight systems (7-14) use plowing as the primary tillage operation. For no-till, direct seeding, hill direct seeding, throwing transplanting were adopted. And following plowing operation, direct seeding, transplanting and throwing transplanting were adopted. For each system, the harvesting operation can chose either combine harvesting or reaping and threshing. Hence systems (1, 3, 5, 7, 9, 11, and 13) adopted combine harvesting, systems (2, 4, 6, 8, 10, 12, and 14) adopted reaping and threshing.

Table 1 Different Mechanical Production Systems of Paddy Rice in South China

Systems	Tillage	Planting	Harvesting
System1	No-till	Direct seeding	combine harvesting
System2	No-till	Direct seeding	reaping +threshing
System3	No-till	Precise Direct seeding	combine harvesting
System4	No-till	Precise Direct seeding	reaping +threshing
System5	No-till	Throwing transplanting	combine harvesting
System6	No-till	Throwing transplanting	reaping +threshing
System7	Plowing	Direct seeding	combine harvesting
System8	Plowing	Direct seeding	reaping +threshing
System9	Plowing	Blanket-type seedling nursery +transplanting	combine harvesting
System10	Plowing	Blanket-type seedling nursery +transplanting	reaping +threshing
System11	Plowing	Seeding establishment in field+ transplanting	combine harvesting
System12	Plowing	Seeding establishment in field+ transplanting	reaping +threshing
System13	Plowing	Pot seedling nursery +throwing transplanting	combine harvesting
System14	Plowing	Pot seedling nursery +throwing transplanting	reaping +threshing

According to the survey, the tillage operation was basically mechanized using tractors and matching implements or self-propelled tillage machine. No-till operation is this area only occupied 0.29% of the mechanical tillage area (MOA). For paddy rice planting, 23.21% of the participants directly seeded, of which, only 23.08% was done mechanically due to lack of suitable machinery. Transplanting was used by 74.89% of the participants, 32.97% of which was done mechanically. The transplanter used most commonly in this region is the four row walking type, with a capacity of 0.8-1.0 hectares per day, depending on the weather condition and the skill of operator. Only 1.9% of the survey participants used throwing transplanting, and all of which is done manually due to the lack of a commercially available throwing transplanting machine. For paddy rice harvesting, 94.80% of the participants harvest with a combine

harvester, the remaining 5.2% manually reap and thresh with stationary threshers, as shown in Table2.

Table2 Technologies adoption ratio and mechanical level

Operations	Technologies	Adoption percentage Pi	mechanization level of the technology
Tillage	No-till	3.42	—
	Plowing	96.58	83.15
Planting	Direct seeding	23.21	23.08
	Transplanting	74.89	32.97
	Throwing transplanting	1.90	2.00
Harvesting	Combine harvesting	94.80	100.00
	Reaping and threshing	5.20	100.00

Economic analysis of different field operation system

In examining the rate of acceptance of new agricultural technology or machinery, profitability is important over a wide range of cultural differences (Schultz, 1964). Reduction of operation costs is often a prime objective of mechanization. In arable farming, there are circumstances in which the introduction of mechanized methods can clearly result in reduced total production cost (Culpin, 1975). The way this is brought about is by reducing the labor input, especially in double cropping region, where the labor cost for paddy rice production tends to be higher than machinery costs.

Cost Analysis

The cost of production systems includes machinery operational cost and other cost. Operational costs includes fuel expense, maintenance expense, depreciation expense, labor expense for machinery; loan expense and insurance expense; other costs includes seeds, seed bowls or trays; fertilizers and chemical. Since farmers hire machinery operation, machinery operation custom rates were used instead of machinery operational costs.

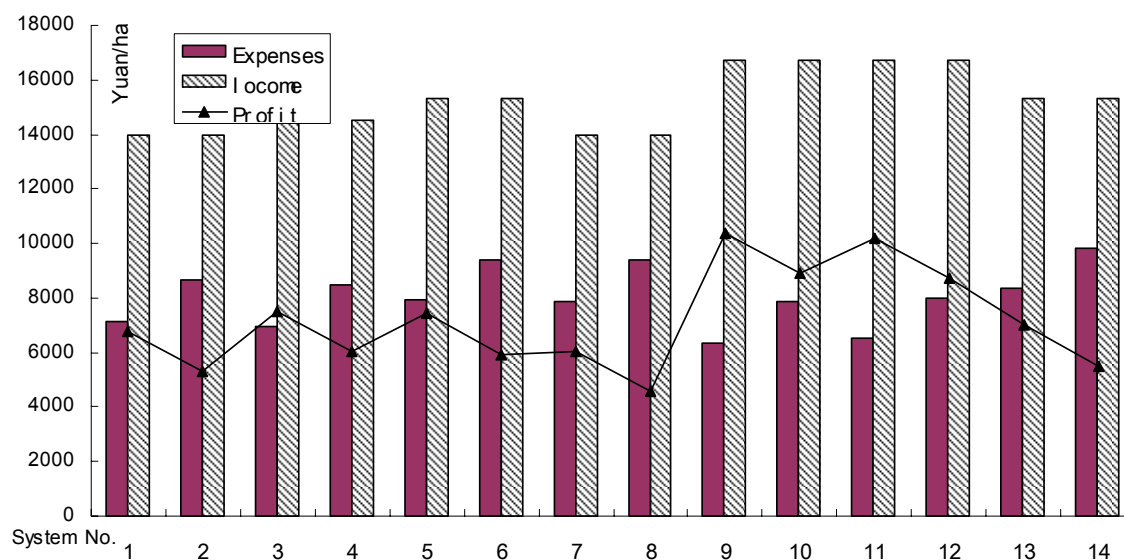


Figure 2 Estimated expenses, income and profit of the 14 different production systems

From the survey, the average cost for plowing was CNY 750 (US\$113.64) per hectare with a standard deviation of was CHY 103.05/ha, the average cost of planting for direct seeding and throwing transplanting was CNY 450 (US\$68.18) per hectare with a standard deviation of 101.34/ha; The average cost of transplanting was CNY 900 (US\$136.36) per hectare with a standard deviation of 105.68. The average cost for combine harvesting was CNY1265.55 (US\$191.75) per hectare, standard deviation was 185.43/ha, as shown in Table 3.

Among these production systems, systems 6, 8 and 14 have the highest cost, as shown in Figure 2. The difference of costs between production systems lies in the operational cost and other costs. Compared with plowing operation, no-till operation reduces the cost of machinery and labor cost, thus the tillage cost of systems 1-6 are lower than other systems. Compared with transplanting, direct seeding and throwing transplanting have higher capital cost, because of the disordered planting, seedlings in the field are not in rows, which requires more manual labor to do field management, and more chemicals to control insects and weeds, as shown in Figure 3. Compared with reaping and threshing, combine harvesting requires less manual labor in the operation, and the machinery custom rates are a lower cost, thus the harvesting costs of systems 1, 3, 5, 7, 9, 11 and 13 are lower than others.

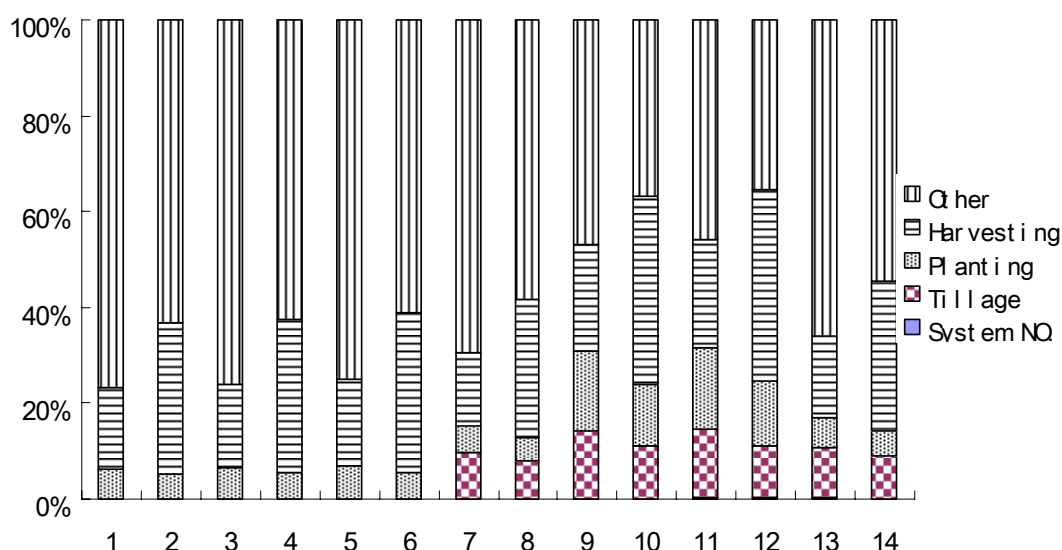


Figure 3 Individual expenses categories as a proportion of the total production cost by system.

Benefit Analysis

The yields of the systems were obtained from the survey. The yields of systems using direct seeding and throwing transplanting are lower than those using transplanting. The national rice procurement prices were used to do economic benefit analysis. In 2010, the price of early rice is CNY 93 (US\$ 14.09) for 50 kg, and the price of late rice is CNY 97 (US\$ 14.70) for 50 kg (NDRC, 2010). The net profit was calculated from the rice value minus the production costs. Systems 9 and 11 obtained a higher net profit than other systems. The highest profit is CNY 10,389.45 per hectare(US\$1574.16/ha) belongs to system 9, which includes plowing for tillage, followed with blanket-type seedling establishment and transplanting, then chemical application, and combine harvesting. Although the systems using plowing and transplanting have higher

seed bowl/tray costs and seedling establishment costs, they have lower capital costs and higher yields.

Table 3 Costs of Different Paddy Rice Mechanical Production Systems															CNY/ha
	System No	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tillage	No-till	0.00	0.00	0.00	0.00	0.00	0.00	—	—	—	—	—	—	—	—
	Plowing	—	—	—	—	—	—	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00
Planting	Direct seeding	450.00	450.00	—	—	—	—	450.00	450.00	—	—	—	—	—	—
	Hill direct seeding	—	—	450.00	450.00	—	—	—	—	—	—	—	—	—	—
	Throwing transplanting	—	—	—	—	450.00	450.00	—	—	—	—	—	—	450.00	450.00
	Transplanting	—	—	—	—	—	—	—	—	900.00	900.00	900.00	900.00	—	—
	Blanket-type seedling establishment	—	—	—	—	—	—	—	—	900.00	900.00	—	—	—	—
	Pot seedling establishment	—	—	—	—	1200.00	1200.00	—	—	—	—	—	—	1200.00	1200.00
	Seeding establishment in field	—	—	—	—	—	—	—	—	—	—	1200.00	1200.00	—	—
	Harvesting	Combine harvesting	1265.55	—	1265.55	—	1265.55	—	1265.55	—	1265.55	—	1265.55	—	1265.55
Reaping +threshing		—	2700.00	—	2700.00	—	2700.00	—	2700.00	—	2700.00	—	2700.00	—	2700.00
Other cost	Fertilizer	1136.70	1136.70	1136.70	1136.70	952.20	952.20	1136.70	1136.7	708.00	708.00	708.00	708.00	952.20	952.20
	Chemical	758.10	758.10	758.10	758.10	517.05	517.05	758.10	758.10	353.40	353.40	353.40	353.40	517.05	517.05
	Seed	240.00	240.00	240.00	240.00	217.50	217.50	240.00	240.00	211.50	211.50	207.30	207.30	217.50	217.50
	Seed bowl/seed tray	—	—	124.50	124.50	—	—	—	—	124.50	124.50	—	—	—	—
	Labor	3300.00	3300.00	3000.00	3000.00	3300.00	3300.00	3300.00	3300.00	1137.60	1137.60	1137.60	1137.60	3000.00	3000.00
Total Cost		7150.35	8650.35	6974.85	8474.85	7902.3	9402.30	7900.35	9400.35	6350.55	7850.55	6521.85	8021.85	8352.30	9852.30
Yield(kg/ha)		7500.00	7500.00	7800.00	7800.00	8250.00	8250.00	7500.00	7500.00	9000.00	9000.00	9000.00	9000.00	8250.00	8250.00
Rice Value(Yuan/ha)		13950.00	13950.00	14508.00	14508.00	15345.00	15345.00	13950.00	13950.00	16740.00	16740.00	16740.00	16740.00	15345.00	15345.00
Net profit		6799.65	5299.65	7533.15	6033.15	7442.70	5942.70	6049.65	4549.65	10389.45	8889.45	10218.15	8718.15	6992.70	5492.70

Factors affecting adoption of mechanical systems for field operations

According to the cost and benefit analysis, some of the systems can obtain high economic benefit; however, in practice, other systems are still adopted. In order to promote the adoption of beneficial production systems, several other factors influencing new agricultural technology or machinery adoption should be considered:

1. Paddy rice production conditions

The paddy rice production environment is complicated in the double-cropping region in south China, not only because of the weather, but also because of the terrain which affects field size and field location. According to the survey, 72.32% of participants in the survey had field sizes smaller than 3 hectares, among which 74% were less than 1 hectare. 67.96% of the fields were located in hilly and mountain areas, with single field sizes as small as 0.1 hectare. Planting scale does not necessarily affect the profitability, but in large size and plain fields, mechanized systems can achieve high efficiency.

2. Education level of farmers

Acquired capabilities of farmers are of primary importance in modernizing agriculture, and these capabilities, like capital goods, are also means of production (Schultz, 1964). Farmers need to have the capability to manage machinery operation and to maintain the machinery. The efficient use of complex equipment often increases substantially as farmers who are accustomed to using one type of complex equipment can quickly learn to get the best performance out of others (Culpin, 1975). Of the participants in the survey, 81.25% had a middle school level of education, and 40.18% of them were over 50 years old. These factors are an important part of the explanation of the mechanization rate in the double-cropping region in south China.

Table 3 Demographic Information of Survey participants unit: %

Age group(yrs old)		Education level		Work status	
20~29	7.14	Primary school (6years)	12.50	Farmers with many machinery and custom service	28.57
30~39	16.07	Middle school (9years)	68.75	Farmers planting large area of rice	9.82
40~49	36.61	High school (12 years)	16.07	Members of agricultural machinery cooperatives	17.86
50~59	25.89	Technical secondary school (12 years)	1.79	County level agricultural machinery professionals	2.68
≥ 60	14.29	College(15-16 years)	0.89	Ordinary farmer	43.75

3. Economic condition of farmers

According to China Statistical Yearbook 2010, the per capita net income of rural households in double-cropping region varies substantially with the highest income in Guangdong Province, at CNY 6906.93 (US\$ 1,046.50) and the lowest in Guangxi Zhuang autonomous region, amounted with CNY 3980.44 (US\$ 603.10). The income in four provinces and regions are lower than national average, which is CNY 5153.17(US\$ 780.78) Low net income limits farms' purchasing ability. The sales price, for example, of a Yanmar Ce-2M semi-feed 2 rows combine harvester manufactured in China is CNY 116,500(US\$17, 651). If the farm applies for a 10 year agricultural loan which has a 4.2% interest rate, they would need to pay back CNY 17,579 (US\$ 2,663) per year, which is 64% of the total annual net income of a four person family in Guangdong Province, and over 100% of the total net income of a four person family in Guangxi Zhuang autonomous region. Clearly, this would not be affordable on average apart from substantial government subsidies.

4. Custom machinery services

Because of the difficulty for individual farmers to finance the purchase of machinery, another possibility is for neighboring farmers to share the cost and use of machines (Culpin, 1975). The development of custom machinery services in double cropping regions allows farmers to hire field operation. For comparison, manual labor costs over CNY 4,500(US\$681.82) to harvest a hectare which is much higher than mechanical harvesting, the price of which is CNY 1200-1800(US\$181.82-272.73) per hectare.

In double-cropping areas in south China, environmental and socio-economic conditions of rice production are complicated, fields are small size, and farmers have limited financial resource to adopt advanced technologies and machineries. All the mechanical methods or production systems will coexist for a period.

Conclusion

Improving the field operation systems for double-cropped paddy rice production mechanization in south China is a complex process. Many direct and indirect affecting factors need to be considered to reduce the cost of paddy rice production and increase the income of farmers. This study investigated the profitability of different mechanical systems of field operations for double-cropping paddy rice production. Several conclusions can be drawn from the study:

1. There are all together 14 different machinery systems existed in the double-cropping region in south China. For tillage, there were no-till and plowing operations; for planting, there were direct seeding, transplanting and throwing transplanting; for harvesting, combine harvesting and reaping and threshing were used.
2. From a profitability perspective, the best mechanical field operation systems for double-cropping paddy rice production in south China were systems 9 and 11, using plowing as tillage operation, blanket-type or open-field seedling establishment, then followed with transplanting and combine harvesting to do the harvest.
3. Most of the current farmers are over 40 years old with a middle school education level; the field scale is generally smaller than 3 hectares, and most of the fields are located in hilly and mountainous areas. There is a great gap between machinery price and the income of farmers. All of these factors constrain the adoption of new technologies and agricultural machinery.
4. More samples and comparison field experiment can improve the accuracy of analysis on different field operations systems under various socio-economic conditions.

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Appendix

Agricultural Technology Integration Questionnaire

1. Gender: _____, Age: ____.

2. Work Experience:

- ☐ farmers providing machinery operation service;
- ☐ farmers have large planting area;
- ☐ managers of custom agricultural machinery cooperatives;
- ☐ members of custom agricultural machinery cooperatives;
- ☐ county machinery staff;
- ☐ manager of farm;
- ☐ professional in farm;
- ☐ ordinary peasant;
- ☐ others_____.

3. Education level:

- ☐ primary school,
- ☐ Middle School,
- ☐ High School,
- ☐ Technical secondary school,
- ☐ College.

4. Terrain of the fields:

- ☐ plain,
- ☐ hilly area,
- ☐ mountain area.

5. Scale of the fields: the smallest field is__ mu, the largest field is__ mu, average scale is__ mu.

6. Cropping culture:

- ☐ one crop a year;
- ☐ double cropping;
- ☐ 3 crops in 2years;
- ☐ others .

7. Is there any tractor road around the fields? ☐ Yes, ☐ No.

Is it easy to transfer machinery? ☐ Yes, ☐ No

If you want, please leave your

Name:

Zip code:

Address:

Phone:

8. House hold income in 2009: family member__persons, total income__Yuan,
including: Rice planting__Yuan, part-time work__Yuan, machinery operation service
custom__Yuan, others__Yuan.
9. House hold expense in 2009: total expense is__Yuan,
including: machinery purchase__Yuan, maintenance__Yuan, machinery operation service
hiring__Yuan, seeds, fertilizers and insecticides____Yuan, others__Yuan.

10. Paddy rice planting area, yield and mechanical production area unit: mu

Paddy rice		planting area	yield (kg/mu)	mechanical tillage	mechanical planting	mechanical harvesting (include reap and thresh)
include	early					
	late					

11. Method and machinery for tillage :

(1)If use manual tillage, a farmer can cultivate__mu per day, labor cost is__Yuan per mu.

(2) If mechanical tillage is used, machinery used was :

- ☐ micro-size cultivator,
- ☐ paddy field cultivator,
- ☐ boat tractor,
- ☐ rotavator,
- ☐ moldboard plow,
- ☐ Engine-driven harrow,
- ☐ others .

The model is____, will upgrade it in__years, purchase price is __Yuan, Subsidy ratio is
____%, Capacity is____mu per hour, fuel consumption is____liter per mu.

(3)Tractor used was__h.p, will upgrade it in__years, purchase price is__Yuan, Subsidy
ratio is____%, Capacity is__mu per hour, fuel consumption is__liter per mu, salary for
operator is__Yuan per mu, If provide machinery service custom, the price is __Yuan per mu.

12. Method and machinery for planting:

(1) Which method do you use:

- ☐ transplanting,
- ☐ direct seeding.

(2) Methods of seedling establishment:

- ☐ Blanket-type seedling establishment(☐soft bowl, ☐hard bowl)
- ☐ Pot seedling establishment,
- ☐ Seeding establishment in field,

Cost of seedling establishment ____Yuan per mu.

(3) Manual operation

- ☐ Manual direct seeding, a farm can finish____ mu per day , labor price is__Yuan per mu;
- ☐ Manual transplanting, a farm can finish____mu per day, labor price is ____Yuan per mu;
- ☐ Manual throwing transplanting, a farm finish____mu per day, labor price is__Yuan per mu.

(4) Mechanical operation

If mechanical direct seeding, machinery used was:

- ☐ Precise hill direct seeder,
- ☐ Direct seeder,
- ☐ Multifunctional direct seeder.

If mechanical throwing transplanting, machinery used was:

- ☐ backpack throwing transplanting machine,
- ☐ riding type pot seedling throwing transplanting machine.

If mechanical transplanting, machinery used was:

- ☐ walking type (☐ 2rows, ☐ 4rows, ☐ 6rows) ,
- ☐ riding type (☐ 4rows, ☐ 6rows, ☐ 8rows) .

The model is____, will upgrade it in____years, purchase price is____Yuan, Subsidy ratio is____%, Capacity is____mu per hour, fuel consumption is____liter per mu, salary for operator is____Yuan per mu, If provide machinery service custom, the price is____Yuan per mu.

Do you adopt machinery operation custom? ☐ yes☐ No.

Price for transplanting is____Yuan per mu.

(5) Which method is better and the reason?

- ☐ mechanical direct seeding,
- ☐ mechanical transplanting,

14. Method and machinery for harvesting:

(1)If manual harvesting, a farmer can harvest____mu per day, labor cost is____Yuan per mu.

(2)If combine harvesting, the machinery used was:

- ☐ Combine harvester(☐ small size, ☐ large size) ;
- ☐ Semi-feed combine(☐ 2rows, ☐ 4rows) ;

The model is____, will upgrade it in ____ years, purchase price is____Yuan, subsidy ratio is____%, capacity is____ mu per hour, fuel consumption is ____liter per mu, salary for operator is____Yuan per mu, If provide machinery operation to other farmers, the price is ____Yuan per mu.

(3) If reaping and threshing, the machinery used was:

- ☐ Mechanical swather,

☐ Mechanical thresher,

the model is_____, will upgrade it in_____years, purchase price is_____Yuan, subsidy ratio is _____%, capacity is_____mu per hour, fuel consumption is_____liter per mu, salary for operator is_____Yuan per mu.

15. Method and machinery for post-harvest processing:

☐ If open air drying,

labor price is _____Yuan per day.

☐ If dryer is adopted,

The model is_____, will upgrade it in_____years, purchase price is_____Yuan, subsidy ratio _____%, capacity is_____tons per time, and electricity consumption is_____kW.h per ton. If provide machinery operation to other farmers, the price is_____Yuan per ton.

16. Based on cost reduction, what kind of machinery or technology can make improvement?

17. What is the other machinery needed, like multifunctional machinery or dryer?